Avoiding Pitfalls in the Development of Phosphorus Removal Feasibility Studies and Discharge Optimization Plans

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Outline

1) Waste Characterization
   a. What? And Where?
   b. When?
   c. How?
   d. Why?
2) Jar Testing
3) Screening of Alternatives
4) Pilot Testing
5) Economic Evaluation
1. Waste Characterization

What?

**Pitfall**

Are assumptions being made based on limited data and rule of thumb ratios about ‘quality’ of substrate?

- BOD5/TP
- COD/TP
- BOD5/NH3-N

<table>
<thead>
<tr>
<th>Types of BRP Process</th>
<th>BOD$_5$/$\Delta$P Ratio (mg BOD$_5$/mg-P)</th>
<th>COD/$\Delta$P Ratio (mg COD/mg-P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High efficiency (e.g., A/O without nitrification, VIP, UCT)</td>
<td>15-20</td>
<td>26-34</td>
</tr>
<tr>
<td>Moderate efficiency (e.g., A/O and A2o with nitrification)</td>
<td>20-25</td>
<td>34-43</td>
</tr>
<tr>
<td>Low efficiency (e.g., Bardenpho)</td>
<td>&gt;25</td>
<td>&gt;43</td>
</tr>
</tbody>
</table>

1. Waste Characterization

What?

Example of BOD5/TP Histogram and Probability Distribution

Pitfall
Are outliers being identified – and how?

Sanity Check
1. Waste Characterization

What?

A better approach is to speciate the important parameters to better understand the ‘quality’ of substrate.

- COD
- TP
- TKN

Example of PCE Speciation from data collected during Pilot Study
1. Waste Characterization

What and Where?

- Influent
- PCE
- FCE
- Effluent
- Filtrate, Centrate

Pitfall

**Temporal Concerns:** Are there variations between collected data and instrumentation?
## 1. Waste Characterization

### What and Where?

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RAW INFLUENT:</strong></td>
<td></td>
</tr>
<tr>
<td>Flow (average daily)</td>
<td></td>
</tr>
<tr>
<td>TSS</td>
<td></td>
</tr>
<tr>
<td>VSS</td>
<td>For calculation of ISS</td>
</tr>
<tr>
<td>COD (total)</td>
<td></td>
</tr>
<tr>
<td>COD (GF filtrate)</td>
<td>For calculation of influent solids COD/VSS</td>
</tr>
<tr>
<td>fFCOD</td>
<td>For RBCOD</td>
</tr>
<tr>
<td>BOD₅ (total)</td>
<td>COD/BOD for estimating inert particulate COD</td>
</tr>
<tr>
<td>VFA</td>
<td>Analytical Procedure not the same as VFA in Digester</td>
</tr>
<tr>
<td>TKN (total)</td>
<td></td>
</tr>
<tr>
<td>TKN (GF filtrate)</td>
<td>For calculation of influent solids N/VSS</td>
</tr>
<tr>
<td>Ammonia</td>
<td></td>
</tr>
<tr>
<td>Nitrate</td>
<td>Spot checks - usually zero</td>
</tr>
<tr>
<td>TP</td>
<td></td>
</tr>
<tr>
<td>Ortho-P (PO₄-P)</td>
<td></td>
</tr>
<tr>
<td>Alkalinity</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td></td>
</tr>
</tbody>
</table>
# 1. Waste Characterization

## What and Where?

### ACTIVATED SLUDGE PROCESS:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLSS</td>
<td>Profile in step feed systems</td>
</tr>
<tr>
<td>MLVSS</td>
<td></td>
</tr>
<tr>
<td>D.O.</td>
<td>Zone to zone, and variation over 24 hours</td>
</tr>
<tr>
<td>RAS flow</td>
<td>Details of flow-pacing</td>
</tr>
<tr>
<td>RAS TSS</td>
<td></td>
</tr>
<tr>
<td>WAS flow</td>
<td>Details of intermittent wasting</td>
</tr>
<tr>
<td>WAS TSS*</td>
<td>May duplicate RAS TSS</td>
</tr>
<tr>
<td>Mixed Liquor recycle flow(s)</td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
</tr>
</tbody>
</table>

### SECONDARY EFFLUENT:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td></td>
</tr>
<tr>
<td>COD (total)</td>
<td></td>
</tr>
<tr>
<td>ffCOD</td>
<td>For RBCOD</td>
</tr>
<tr>
<td>BOD$_x$ (0.45 (\mu)m filtrate)</td>
<td></td>
</tr>
<tr>
<td>TKN (0.45 (\mu)m filtrate)</td>
<td></td>
</tr>
<tr>
<td>Ammonia</td>
<td></td>
</tr>
<tr>
<td>Nitrate</td>
<td></td>
</tr>
<tr>
<td>Nitrite</td>
<td>Spot checks - should be zero</td>
</tr>
<tr>
<td>TP (0.45 (\mu)m filtrate)</td>
<td></td>
</tr>
<tr>
<td>Ortho-P (PO$_4$-P)</td>
<td></td>
</tr>
<tr>
<td>Alkalinity</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td></td>
</tr>
</tbody>
</table>
## 1. Waste Characterization

### What and Where?

<table>
<thead>
<tr>
<th>Thickening and BFP Underflows:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>Details of intermittent return</td>
</tr>
<tr>
<td>TSS</td>
<td>Sampling needs depend on stream type</td>
</tr>
<tr>
<td>VSS</td>
<td></td>
</tr>
<tr>
<td>COD (total, GF filtrate)</td>
<td></td>
</tr>
<tr>
<td>ffCOD, VFA</td>
<td>For fermenter streams</td>
</tr>
<tr>
<td>$BOD_5$ (total)</td>
<td></td>
</tr>
<tr>
<td>TKN, NH$_3$, NO$_3$</td>
<td></td>
</tr>
<tr>
<td>TP, PO$_4$P</td>
<td></td>
</tr>
<tr>
<td>Alkalinity</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td></td>
</tr>
</tbody>
</table>
1. Waste Characterization

When?

Design Sampling Program to Address Temporal Concerns. This may require multiple sample periods or an extended sampling period.

**Pitfall**
Are Seasonal Variations Being Considered? And the impacts of varying flows: dry weather, wet weather, seasonal fluctuations, industrial loadings?

**Pitfall**
Temporal Concerns: Are there variations between collected data and instrumentation?
1. Waste Characterization

How?

- Composite
- Grab
1. Waste Characterization

Why?

- Garbage In = Garbage Out
- Investing Millions of Public Dollars
- Quest for Cost Effective Solutions
2. Jar Testing

- Jar Testing is a Must for Final Design
- Locations of Dosing
  - PCE
  - MLSS
  - FCE
  - Filtrate from Dewatering
- Alum or Ferric Chloride
  - For Plants with Anaerobic Digestion, Ferric May be a Better Choice
3. Screening of Alternatives

Results of Waste Characterization coupled with Modeling

Benefits of Using Models for Process Design

The traditional approach for designing biological nutrient removal systems (e.g., for nitrification) was to determine solids residence time (SRT) based on kinetic equations, then to apply a safety factor based on engineering judgment. The new method currently being used by design engineers is to determine site specific nitrification kinetics based on influent quality and perform dynamic modeling of the system to capture variability. Lower safety factors can be used in design with more confidence that the plant can achieve the desired treatment objectives under a variety of operating conditions.
3. Screening of Alternatives

- Steady State
- Dynamic
- Identify KPI’s
- Calibration
- Validation

Pitfall
Are recycle flows from batch processes properly accounted for…centrate…filtrate?

Pitfall
After model has been calibrated, has it been checked using an independent data set? Validation.
### Steady State Modeling of Existing Conditions - Calibration

#### Key Process Indicators

<table>
<thead>
<tr>
<th></th>
<th>10%</th>
<th>-1 std. dev.</th>
<th>Measured Median</th>
<th>+1 std. dev.</th>
<th>90%</th>
<th>Modeled</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EFFLUENT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cBOD</td>
<td>2.00</td>
<td>2.04</td>
<td>2.69</td>
<td>3.34</td>
<td>4.00</td>
<td>1.39</td>
<td>NA</td>
</tr>
<tr>
<td>COD</td>
<td>8.00</td>
<td>12.97</td>
<td>19.76</td>
<td>26.56</td>
<td>30.30</td>
<td>22.54</td>
<td>14%</td>
</tr>
<tr>
<td>TSS</td>
<td>1.00</td>
<td>1.42</td>
<td>2.88</td>
<td>4.34</td>
<td>5.40</td>
<td>2.98</td>
<td>-3%</td>
</tr>
<tr>
<td>TN</td>
<td>16.10</td>
<td>17.55</td>
<td>20.30</td>
<td>23.06</td>
<td>24.20</td>
<td>27.03</td>
<td>-33%</td>
</tr>
<tr>
<td>Ammonia-N</td>
<td>0.06</td>
<td>-</td>
<td>0.27</td>
<td>0.42</td>
<td>0.66</td>
<td>0.43</td>
<td>-64%</td>
</tr>
<tr>
<td>TP</td>
<td>1.91</td>
<td>1.91</td>
<td>2.71</td>
<td>3.52</td>
<td>3.65</td>
<td>3.29</td>
<td>-21%</td>
</tr>
<tr>
<td><strong>SOLIDS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-PRIMARY SLUDGE</td>
<td>2.95</td>
<td>3.08</td>
<td>4.04</td>
<td>5.01</td>
<td>4.97</td>
<td>4.16</td>
<td>-3%</td>
</tr>
<tr>
<td>D-PRIMARY SLUDGE</td>
<td>2.33</td>
<td>2.53</td>
<td>4.02</td>
<td>5.51</td>
<td>5.96</td>
<td>4.40</td>
<td>-9%</td>
</tr>
<tr>
<td>GBT TWAS</td>
<td>3.99</td>
<td>4.04</td>
<td>5.13</td>
<td>6.22</td>
<td>6.28</td>
<td>5.27</td>
<td>-3%</td>
</tr>
<tr>
<td>CENTRIFUGE CAKE</td>
<td>20.55</td>
<td>20.95</td>
<td>23.15</td>
<td>25.35</td>
<td>24.90</td>
<td>23.00</td>
<td>1%</td>
</tr>
<tr>
<td>MLSS</td>
<td>2,810</td>
<td>2,763</td>
<td>3,295</td>
<td>3,827</td>
<td>4,042</td>
<td>3,163</td>
<td>4%</td>
</tr>
<tr>
<td>MLVSS</td>
<td>2,385</td>
<td>2,328</td>
<td>2,753</td>
<td>3,179</td>
<td>3,352</td>
<td>2,708</td>
<td>2%</td>
</tr>
<tr>
<td>RAS</td>
<td>6,311</td>
<td>6,368</td>
<td>7,804</td>
<td>9,241</td>
<td>9,790</td>
<td>7,855</td>
<td>-1%</td>
</tr>
<tr>
<td>GBT FILTRATE SOLIDS</td>
<td>1,000</td>
<td>1,036</td>
<td>1,208</td>
<td>1,380</td>
<td>1,400</td>
<td>1,282</td>
<td>-6%</td>
</tr>
<tr>
<td>CENTRATE SOLIDS</td>
<td>1,600</td>
<td>1,666</td>
<td>2,132</td>
<td>2,302</td>
<td>2,500</td>
<td>2,164</td>
<td>-2%</td>
</tr>
</tbody>
</table>
3. Biological Process Pilot Study - Example

- Two parallel treatment trains
  - September 1 – October 31, 2015
- Train 1 – Single Stage Nitrification
- Train 2 – Bio P Process
  - Pass 1 operated as an anaerobic zone
  - ORP probe installed at beginning and mid pass and end of Pass 1

**Pitfall**
Can you pilot? Minimal Investment May Pay Dividends.
3. Biological Process Pilot Study - Example

### Pilot Study Results

<table>
<thead>
<tr>
<th>Average Final Clarifier Effluent Concentrations, mg/l</th>
<th>Influent</th>
<th>Train 1</th>
<th>Train 2 - Pilot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured</td>
<td>Removed</td>
<td>Measured</td>
</tr>
<tr>
<td>Total P</td>
<td>6.36</td>
<td>2.50</td>
<td>3.86</td>
</tr>
<tr>
<td>Soluble P</td>
<td>4.16</td>
<td>2.03</td>
<td>2.13</td>
</tr>
<tr>
<td>Particulate P</td>
<td>2.20</td>
<td>0.47</td>
<td>1.73</td>
</tr>
</tbody>
</table>

- *Tetrasphaera* sp. in symbiosis with *Accumulibacter* at low ORPs
- 1.4 mg/l (441 lbs/d) additional SP removed with Bio-P process.
  - If chemical were used to remove 441 lbs/d of P, 2,022 gpd at 3:1 mole Fe: mole P. 20 yr PW of $10.7 million.
- Baffles need to prevent bleed back of air from Pass 2 to Pass 1
3. Biological Process Pilot Study - Example

<table>
<thead>
<tr>
<th>ORP (mV)</th>
<th>Process</th>
<th>Electron Acceptors</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>+300</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+200</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+100</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>4</td>
<td></td>
<td>Oxic or Aerobic</td>
</tr>
<tr>
<td>-100</td>
<td>5</td>
<td></td>
<td>Anoxic Anaerobics</td>
</tr>
<tr>
<td>-200</td>
<td>6</td>
<td></td>
<td>Fermentive Anaerobic</td>
</tr>
<tr>
<td>-300</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-400</td>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Organic Carbon Oxidation
2. Polyphosphate Development
3. Nitrification
4. Denitrification
5. Polyphosphate Breakdown
6. Sulfide Formation
7. Acid Formation
8. Methane Formation
4. Economic Evaluation

- Present Worth Evaluation
- Capital Costs
- M & O Costs
  - Chemical
  - Power
  - Maintenance Manpower
  - Excess Sludge
  - Replacement Costs

**Pitfall**
Not taking into account inflation. For example, a $10 Million Project with $350,000 in Annual M&O. (5% interest, 3% Inflation, 20 years)

Has a PW of $15.5 M

$14.4 if inflation is ignored.
DISCUSSION AND